London
CANADA

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July 26, 2011

P. McNally
Executive Director, Planning and Environmental and Engineering Services

I hereby certify that the Municipal Council, at its session held on July 25, 2011 resolved:

47. That, on the recommendation of the Executive Director of Planning, Environmental and Engineering Services, the following actions be taken with respect to the completion of the Climate Change Adaptation Strategy Phase 1 that:

(a) the "Updated Rainfall Intensity Duration Frequency Curves for the City of London under the Changing Climate Study" developed by UWO in collaboration with Delcan, **BE RECEIVED**;

(b) the "City of London: Vulnerability of Infrastructure to Climate Change" study developed by UWO in collaboration with Delcan, Ottawa Office **BE RECEIVED**;

(c) Planning, Environmental and Engineering Services **BE DIRECTED** to proceed with consultation with the public and interested parties with respect to increasing the City's existing Intensity Duration Frequency (IDF) Curves prior to undertaking the next steps as identified in (d), below;

(d) Planning, Environmental and Engineering Services **BE DIRECTED** to proceed with the next set of Climate Change Adaptation Strategy studies as follows:

- (i) update the Water Resources Components of the existing Subwatershed Studies such as the Dingman Creek, Stoney Creek, Mud Creek, Medway Creek and Pottersburg Creek using the Climate Change Upper Bound (CC_UB) scenarios in order to develop climate change Adaptation Policies; assess the impacts of these scenarios on the City's infrastructure and develop mitigation strategies;
- (ii) develop the Water Resources Components and slope stability evaluation for a Central Thames Subwatershed Study using the Climate Change Upper Bound (CC_UB) scenarios in order to develop climate change Adaptation Policies, assess the impacts of these scenarios on the City's infrastructure and develop mitigation strategies;
- (iii) develop a Green Infrastructure Plan to incorporate an environmental/ecological approach to water resources management;
- (iv) develop a Long-Term Climate Change Adaptation Strategy on the basis of the outputs from studies (i) to (iii); and,
- (v) use of 21% Intensity Duration Frequency (IDF) for modeling purposes; and

(e) the Civic Administration **BE DIRECTED** to hold a public participation meeting and consult with interested agencies to receive input upon the completion of the subwatershed studies outlined above;

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TO:	**CHAIR AND MEMBERS BUILT AND NATURAL ENVIRONMENT COMMITTEE MEETING ON JULY 18, 2011**
FROM:	**PAT McNALLY P. Eng. EXECUTIVE DIRECTOR OF PLANNING, ENVIRONMENTAL AND ENGINEERING SERVICES**
SUBJECT:	**CLIMATE CHANGE ADAPTATION STRATEGY PHASE 1 COMPLETION**

RECOMMENDATION

That, on the recommendation of the Executive Director of Planning, Environmental and Engineering Services, the following actions **BE TAKEN** with respect to the completion of the Climate Change Adaptation Strategy Phase 1 that:

a) the "Updated Rainfall Intensity Duration Frequency Curves for the City of London under the Changing Climate" developed by UWO in collaboration with Delcan, Study **BE RECEIVED**;

b) the "City of London: Vulnerability of Infrastructure to Climate Change" study developed by UWO in collaboration with Delcan, Ottawa Office **BE RECEIVED**;

c) Planning, Environmental and Engineering Services **BE DIRECTED** to proceed with increasing the City's existing Intensity Duration Frequency (IDF) Curves by 21% and that Civic Administration **BE DIRECTED** to incorporate this change in a phased approach starting with the subwatershed studies outlined below and ultimately adjusting other design standards, planning and Official Plan considerations in dialogue with interest parties; and

d) Planning, Environmental and Engineering Services **BE DIRECTED** to proceed with the next set of Climate Change Adaptation Strategy studies as follows:

(i) update the Water Resources Components of the existing Subwatershed Studies such as the Dingman Creek, Stoney Creek, Mud Creek, Medway Creek and Pottersburg Creek using the Climate Change Upper Bound (CC_UB) scenarios in order to develop climate change Adaptation Policies, assess the impacts of these scenarios on the City's infrastructure and develop mitigation strategies;

(ii) develop the Water Resources Components and slope stability evaluation for a Central Thames Subwatershed Study using the Climate Change Upper Bound (CC_UB) scenarios in order to develop climate change Adaptation Policies, assess the impacts of these scenarios on the City's infrastructure and develop mitigation strategies;

(iii) develop a Green Infrastructure Plan to incorporate an environmental/ ecological approach to water resources management; and

(iv) develop a Long Term Climate Change Adaptation Strategy on the basis of the outputs from studies (i) to (iii).

It being noted that the recommendations identified in the Executive Summary (Appendix A) will be addressed as part of the above noted studies.

PREVIOUS REPORTS PERTINENT TO THIS MATTER

ETC, December 10, 2007, Item 6 – Review of Rainfall Intensity Duration Frequency Curves for City of London under Climate Change

BOC, May 28 2008 – Wastewater and Treatment Emergent Projects (a) - ES2470 Climate Change Strategy

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ETC, July 14, 2008 - Appointment of the consultants for Phase 1 Climate Change Adaptation Strategy

CoW, June 13, 2011 – Verbal Presentation for Phase 1 Completion of Climate Change Adaptation Strategy

BACKGROUND

Purpose:
To report on the completion of the following Council approved studies:
- Phase 1 Climate Change Adaptation Strategy,
- "Updated Rainfall Intensity Duration Frequency Curves for the City of London under Changing Climate" and
- "The City of London Vulnerability of Infrastructure to Climate Change" Study.

Together these studies provide an evaluation of climate change impacts of extreme rainfall events on related municipal design standards for critical infrastructure and make recommendations for the next steps.

In the last 30 years London has had five severe flooding occurrences (March 1977, September 1986, July 2000, April and December 2008). Climate modeling based on more up-to-date rainfall events and patterns suggests that the City of London can expect to experience more frequent and severe precipitation events in the future which may seriously impact various public infrastructure. Current infrastructure was designed and constructed on the basis of standards and codes that were developed decades ago. These standards and codes were based on historic climate and design storms which are no longer representative of the current rainfall patterns. With the changes in these rainfall events/climate patterns, some infrastructure may no longer have the capacity to handle the new rainfall events loads and impacts.

In order to reduce the potential vulnerability to adverse impacts of climate change in particular under extreme rainfall events, it is necessary to anticipate the possible effects, and adapt. Municipal decision's makers and stakeholders must be informed regarding projected effects, and develop suitable measures to deal with the effects of climate change under the extreme rainfall events today and in the future.

Context:
The main objectives of Water Resources Management include ensuring the safety of people and property, maintaining functionality of open watercourses, streams, creeks, rivers and lakes and contribute towards the health and protection of the City's eco/environmental systems. London's municipal infrastructure, which is in place today and planned for the foreseeable future, reflect these objectives to managing urban stormwater.

Design criteria and stormwater pipe sizing generally include an approved standard design rainfall input for a specified return period. Pipes are generally designed to convey the minor peak flows (up to 2-10 year) and overland routes are designed to provide conveyance for the peak flows that cannot be accommodated in the pipe system.

Generally, increased volumes and flows resulting from changes in land use are managed by:
- the implementation of quality, erosion, and quantity/flood control Stormwater Management (SWM) Facilities within or at the downstream end of the storm sewer network; and
- explicit consideration of a major system to convey flows which exceed the capacity of the minor system (pipes and facilities). Specified return periods were typically 2 to 10 years for the minor system and 2 to 250 years for the major system.

In February 2007, the Department of Civil and Environmental Engineering of UWO completed a study related to the Assessment of Risk and Vulnerability to Changing Climatic Conditions within the Thames River Watershed (Study #1). This study was prepared by Dr. Slobodan Simonovic and Predrag Prodanovic. The conclusions of this study identified that:

> *"climate change is expecting to intensify flooding in the basin, thus bringing flows in higher magnitude with more frequent occurrence. Such conditions may demand*

additional investments in flood management infrastructure and may require complete revision of budgets for flood management and yearly maintenance. It may even require retrofitting and replacing current (or even building additional) flood management infrastructure. Engineering design standards in light of changed climatic conditions may also need revision."

After publishing (Study #1), Dr. Slobodan Simonovic presented the main conclusions of this study to the City Council.

The City engaged Dr. Simonovic to undertake a preliminary study of Development of the Intensity Duration Frequency (IDF) Curves for the City of London Under Changing Climate in July 2007 (Study #2). This Study was completed in November 12, 2007.

The results of the Study #2 indicated that rainfall magnitude (and intensity) would be different from historically observed. Design standards for water resources management directly affect storm drainage, stormwater management (SWM) and combined sewer overflow (CSO) and the various elements (e.g. buildings, floodways, streets, culverts, dykes, bridges, wastewater treatment plants etc.). It is anticipated that when these infrastructure elements need to be rebuilt they will need to be designed to incorporate a potentially significant increase in rainfall magnitude and intensity for a range of durations and return periods. This redesign represents major implications on current and future water resources management and critical municipal public infrastructure. The main recommendation from this work was that design standards and guidelines currently employed by the City of London be reviewed and revised in light of the information presented in this report.

In December 2007, Council approved a two-phased Climate Change Adaptation Strategy. In 2008, the City engaged the UWO's Research Team led by Dr. Simonovic, Director of Engineering Studies, Department of Civil and Environmental Engineering, Institute for Catastrophic Loss Reduction and an Engineering Consulting Team – Delcan in order to balance scientific evaluations and the analytical academic review with practical engineering expertise, and to oversee consistency and the implementation of the engineering practices and standards for Phase 1. The resulting studies were the update of "the Rainfall Intensity Duration Frequency Curves for the City of London under Changing Climate" (Study #3) and "The City of London Vulnerability of Infrastructure to Climate Change" (Study #4).

These studies involved a number of engineering and scientific assessment and evaluations to determine the risk, the level of municipal services that the City plans to provide as well as potential impacts on the various elements (e.g. buildings, floodways, streets, culverts, dykes, bridges and sewer design, etc.,) that may occur as a result of these higher intensity storms and are the building blocks to the development and implementation of a Climate Change Adaptation Strategy.

Discussion:
The Executive Summary (Appendix 'A') summarizes the methodology and conclusions from studies 3 and 4. Study #3 recommends that the current IDF curves, used by the City of London be revised to reflect the potential impact of climate change, as the simulation results of the study show that:

1. the rainfall magnitude will be different in the future;
2. the scenarios modeled reveal significant increase in rainfall intensity for a range of durations and return periods; and
3. the increase in rainfall intensity and magnitude has major implications on the ways in which current (and future) municipal water management infrastructure is designed, operated, and maintained.

Comparison between the updated IDF curves and the City's current IDF curves developed by Environment Canada shows an increase that ranges between 11% and 35% with an average increase of approximately 21%. Based on this comparison, it is recommended that the City of London proceed with an increase of the IDF curves by 21% as an interim measure. The direct impacts of this recommendation could translate in an increase on the size/cost of stormwater systems of 15-20%. The benefit of enlarging the facilities is to remain close to the current level of service while taking into account changing climate conditions. This will help to ensure the safety of people and property, while preserving the functionality of open watercourses, streams, creeks, rivers and lakes and protecting the health of eco/environmental systems.

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It is further recommended that the London Development Institute and the London Consultant Engineers of Ontario be advised of this change in standards following Council approval so that they can have adequate time to incorporate this change into their designs for their new subdivisions.

Risk is defined in Study #4 as the intersection of a hazard (flooding) with vulnerability. The risk measures enable conclusions and recommendations to be made regarding the reliability of the infrastructure within the City to adapt to the impact of the changing climate conditions. Study #4 results are meant to identify the areas of high risk within the City and recommend further investigation based on the priority of these high risk areas. The analyses of climate, hydraulic and hydrologic data were used as inputs to assess the risk of public and critical infrastructure. The data considered for infrastructure within the study includes 216 bridges & culverts, 520 km of arterial roads, more than 3,000 buildings within flooded areas more that 1,300 km of sanitary/storm pipe network, 6 pollution control plants and approximately 100 stormwater management facilities.

The Vulnerability of the City of London Infrastructure (Study #4) to flooding is based on two climate scenarios representing the lower and upper bounds of the potential climate impacts named the *climate change lower bound scenario* (CC_LB) and the *climate change upper bound scenario* (CC_UB). These were derived from historical data and the period between 1964 to 2006. Both the 100-year and 250-year return period were selected for use in this study as they are the basis for the current regulatory floodplains enforced by the City of London and the UTRCA. Also considered was the UTRCA historical flooding condition, referred to as the 250 UTRCA scenario.

The information is presented in the form of maps and tables with the maps being broken down into Dissemination Areas (DA) for ease of understanding. A map was produced for each climate scenario modeled. The studies will be posted on the city's SWM Unit website following the BNEC meeting on July 18, 2011.

The main findings of Study #4 are as follows:

- Area behind Broughdale dyke along the North Thames is a major concern;
- Area behind West London Dyke near the downtown Forks is a major concern;
- Pollution control plants (PCPs) are high risk infrastructure;
- Pottersburg Creek southwest of Trafalgar Street and Clarke Road is a significant concern; and
- The Dissemination Area containing the Greenway PCP is a major concern.

Generally, as flooding intensity increases, damages also increase, but the risk index does not always do the same. As risk is a product of probability of the hazard event and potential damages it causes, there are occurrences where high probability of a flood event has a greater influence on risk index than the increase in damages. Thus, it is possible for an event of lower intensity to achieve higher risk indices as observed in this project.

The Study determined that under the 250 UTRCA existing condition scenario, the potential flooding damage to the community is approximately $600M. The 100 year and 250 year Climate Change Upper Bound (CC_UB) scenarios identified potential flooding damage to the community of approximately $1B.

The most critical climate change condition is the 100-year Climate Change Upper Bound (CC_UB) scenario because of the probability of this event occurring 2 ½ times to every time the 250 year event occurs.

Conclusions:
As identified previously, in December, 2007 Council approved a two-phased Climate Change Adaptation Strategy. Phase 1 is now complete and it is recommended that Council receive:

1. "Updated Rainfall Intensity Duration Frequency Curves for the City of London under the Changing Climate" (Study #3)

2. "The City of London: Vulnerability of Infrastructure to Climate Change" (Study #4)

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It is further recommended that Planning, Environmental and Engineering Services Department:

- undertake upgrading of the City's standards of increasing the existing IDF curves by 21% that Civic Administration be directed to incorporate this change in a phased approach starting with the subwatershed studies outlined below and ultimately adjusting other design standards, planning and Official Plan considerations in dialogue with interest parties;
- notify the London Development Institute and the London Consulting Engineers of Ontario of this change in IDF curves; and
- proceed with the following studies:

(i) update the Water Resources Components of existing Subwatershed Studies such as the Dingman Creek, Stoney Creek, Mud Creek, Medway Creek and Pottersburg Creek using the Climate Change Upper Bound (CC_UB) scenarios in order to develop climate change Adaptation Policies, assess the impacts of these scenarios on the City's infrastructure and develop mitigation strategies;

(ii) develop the Water Resources Components and slope stability evaluation for a Central Thames Subwatershed Study using the Climate Change Upper Bound (CC_UB) scenarios in order to develop climate change Adaptation Policies, assess the impacts of these scenarios on the City's infrastructure and develop mitigation strategies;

(iii) the development of a Green Infrastructure Plan to incorporate an environmental/ ecological approach to water resources management; and

(iv) the development of a Long Term Climate Change Adaptation Strategy on the basis of the outputs from studies (i) to (iii).

It being noted that the recommendations identified in the Executive Summary (Appendix A) will be addressed as part of the above noted studies.

Acknowledgements:
This report was prepared by Berta Krichker Manager M. Eng, F.E.C., P. Eng., Manager of Stormwater, Stormwater Management Unit.

SUBMITTED BY:	**RECOMMENDED BY:**
BERTA KRICHKER, M.Eng., F.E.C., P. Eng. **MANAGER OF STORMWATER** **STORMWATER MANAGEMENT UNIT**	**RON STANDISH, P.ENG.** **DIRECTOR, WASTEWATER AND TREATMENT ENVIRONMENTAL AND ENGINEERING SERVICES**

REVIEWED & CONCURRED BY:
PAT MCNALLY, P.ENG. **EXECUTIVE DIRECTOR OF PLANNING, ENVIRONMENTAL AND ENGINEERING SERVICES**

July 11, 2011

Attach: Appendix "A" – Executive Summary

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Executive Summary

The Earth's climate is changing resulting in more frequent extreme rainfall events. Existing municipal infrastructure is designed and constructed based on standards that include historical rainfall events for "design storms" which are no longer representative of the current climate. The infrastructure that was appropriately designed for historical design storms may no longer have the capacity to handle the storms that are now occurring due to the new climatic conditions. Climate modeling suggests that the City of London can expect to experience more frequent and more severe precipitation events in the future. Thus, the City must adapt its policies and procedures related to the infrastructure to consider the more frequent extreme rainfall events and thereby mitigate the risks to the municipality. Since flooding is a natural hazard event of significance to this region, the City commissioned this study to assess the vulnerability of London's public infrastructure to changing climatic conditions.

The study results are meant to identify the areas of high risk within the city and recommend further investigation based on the priority of these high risk areas. The recommendations are also meant to aid in the policy and procedures development as it relates to the design and construction of future municipal infrastructure within the City.

The risks identified in the study are related to the impacts to infrastructure elements only. No social impacts were taken into account in determining the severity of the risks. The recommendations are solely based on the risk of municipal infrastructure in relation to a flood event.

The analyses of climate, hydraulic and hydrologic data were used as inputs to assess the risk of public infrastructure which is defined in more detail under the "Local Infrastructure" section. Two climate change scenarios were considered, representing the lower and upper bounds of the potential climate impacts. With the City of London being within the Thames River drainage basin, the current regulatory floodplain developed by the Upper Thames River Conservation Authority (UTRCA) was also considered as an additional scenario, representing the historical flooding conditions.

The integrated risk assessment procedure developed for this project includes:

1. selection of climate models and scenarios;
2. climate modeling based on the integration of global climate data and historical observations by using a downscaling tool (known as the weather generator) to simulate meteorological data;
3. hydrologic modeling using the "Hydrologic Engineering Center – Hydrologic Modeling System" (HEC-HMS) to transform meteorological data into runoff information, which in turn generates stream flows;
4. hydraulic modeling using the "Hydrologic Engineering Center – River Analysis System" (HEC-RAS) to map floodplains for each climatic scenario;
5. data collection of local infrastructure;
6. the development of flood risk tables and maps to assess the infrastructure risk based on the climate change scenario, and;
7. identification of recommendations.

Climate Modeling

Currently, one of the best ways to study the effects of climate change is to use Global Circulation Models (GCM). These models are the current state of the art in climate science which describe the functioning of the climate system through the use of physics, fluid mechanics, chemistry, as well as other sciences. A traditional way of studying the impacts of climatic change for small geographic areas involves the downscaling of the outputs from GCM (temporally and spatially) from which the user and location specific impacts are derived.

In this study the weather generator approach was used for downscaling the global information to a local scale. This approach takes as inputs historical climatic information, as well as information from the GCM, and generates climatic information for the local weather station. Climate change scenarios are the output of the GCM which do not predict the future but simply offer the possibilities of what may happen in the future following a particular course of action.

Two climate scenarios, named the climate change lower bound scenario (CC_LB) and the climate change upper bound scenario (CC_UB), were derived from the historical data and inputs from the GCM.

The two climate scenarios developed for use in this study were based on local data for the period 1964 to 2006.

Hydrologic Modeling

The US Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) was used to transform the two climate scenarios of meteorological conditions into corresponding runoff. HEC-HMS is a precipitation-runoff model that includes a large set of mix-and-match methods to simulate river basin, channel and water control structures.

The modified meteorological records produced by the climate modeling were used as input into the HEC-HMS to simulate the direct runoff due to precipitation events and translate the runoff into the stream flow. The final model includes 72 sub-basins, 45 reaches, 49 junctions, and 3 reservoirs. The HEC-HMS model provided stream flow data that used directly as input information for the hydraulic modeling component of the study.

Hydraulic Modeling

Stream flow generated by the hydrologic model was used in conjunction with a Digital Terrain Model (DTM) and channel characteristics as input into the Hydrologic Engineering Center's River Analysis System (HEC-RAS) hydraulic modeling program to generate water surface profiles. The extent of flooding and water depth corresponding to different simulated floods are then imported into a Geographic Information System (GIS) environment and are the foundation for the infrastructure risk assessment.

Both a 100-year and 250-year return period floods were selected for use in this study as they are the basis for the current floodplain regulations enforced by the City of London and the Upper Thames River Conservation Authority. This study therefore considered five scenarios (two for the climate change upper bound, two for the climate change lower bound and one for the Upper Thames River Conservation Authority historical flooding conditions):

1. 100-year CC_LB;
2. 100-year CC_UB;
3. 250-year CC_LB;
4. 250-year CC_UB; and
5. 250 UTRCA.

The fifth scenario represents the current floodlines generated by the Upper Thames River Conservation Authority (UTRCA) which are included in the City of London Official Plan. The extent of the floodlines was provided by UTRCA and the data is available for the 250-year return period only.

Local Infrastructure

The study considered the following infrastructure elements:

- transportation infrastructure (including bridges, culverts and arterial roads);
- buildings (residential, commercial and industrial); and
- critical facilities, defined in this study as the buildings which provide essential or emergency services (fire stations, Emergency Management Services (EMS), police stations, hospitals, schools and pollution control plants), flood protection structures, sanitary and storm sewer conveyance networks and the drinking water distribution network.

Each of these infrastructure elements has different failure mechanisms due to flooding.

A summary of the type and quantities of infrastructure data that was considered in the study is presented in the following table.

Infrastructure	Quantity
Bridges & Culverts	216
Arterial Roads	520 km
Buildings	>3,000*
Sanitary/Storm Pipe Network	> 1,300 km
Pollution Control Plants	6
Stormwater Management Facilities	100

*within the floodplain areas under consideration

The study team conducted interviews with knowledgeable staff across the infrastructure categories at the City of London to better understand each system and gather input for the risk analysis. The departments and divisions involved in this process included:

- Risk Management Division;
- Stormwater Management (SWM) Unit
- Planning and Development – Building,
- Transportation Planning and Design,
- Water Operations Division,
- Water Engineering Division,
- Pollution Control Operations,
- Wastewater and Drainage Engineering,
- Environmental Programs and Customer Relations, and
- Corporate Security and Emergency Management Division.

The study team also interviewed experienced and qualified personnel from the UTRCA and at the University of Western Ontario regarding the approach, data inputs and results for this study.

Risk Assessment
The risk assessment methodology produces an integrated risk index for each infrastructure element considered in the study. The risk index allows for the comparison among various geographic locations that may be flooded and is presented in a tabular format and in a spatial (maps) format.

Risk is commonly defined as the product between a hazard and a vulnerability when used in the context of flooding (Apel, 2008). This study measures vulnerability which is defined by Engineers Canada in the context of infrastructure and climate change as "the shortfall in the ability of public infrastructure to absorb the negative effects, and benefit from the positive effects, of changes in the climate conditions used to design and operate infrastructure" (Engineers Canada, 2007).

For each of the five climate scenarios, the Risk Index 'R' is calculated for each infrastructure element. The risk index values are then combined and displayed spatially using GIS in the form of risk maps. Risk is portrayed geographically by Dissemination Areas (DA) classification consistent with Statistics Canada method of representing data. Statistics Canada defines DA as "a small, relatively stable geographic unit comprised of one or more adjacent dissemination blocks". There are 527 DA within the City of London. Each DA is identified by its unique 4-digit code. They remain relatively stable over time and they are considered small enough to remain significant in municipal decision making.

Results
The risk of the City of London Infrastructure to flooding is presented in the form of maps and tables. A map was produced for each of the five climatic scenarios. The Risk Index was calculated for each DA with areas of high risk represented by different shades of colour as indicated in the legend of each map. The Risk Index is represented on the scale between '1' (the highest level of risk) and '0' (no risk). The risk maps are to be used in conjunction with the risk tables to aid in urban planning, emergency management and municipal decision making.

Each scenario has at least one DA for which the risk index value is one. Generally, as flooding intensity increases, the level of damages also increase, but the risk index does not correspond in the same fashion. As risk is a product of the probability of the hazard event and the potential damages it causes, there are occurrences where high probability of a flood event has a greater influence on the Risk Index than the actual increase in damages. Thus, it is possible for an event of lower intensity to achieve a higher Risk Index as observed in this project.

Five analyses were conducted in the study to gain insight into the risk to infrastructure due to flooding as a result of climate change:

Case 1: Contribution of climate change;

Change in risk index between 250 UTRCA scenario and 250 CC_UB scenario

Case 2: Comparison of 100 year climate change events;

Change in risk index between 100 CC_LB scenario and 100 CC_UB scenario

Case 3: Comparison of 250 year climate change events;

Change in risk index between 250 CC_LB scenario and 250 CC_UB scenario

Case 4: Comparison between lower bound scenarios;

Change in risk index between 100 CC_LB scenario and 250 CC_LB scenario

Case 5: Comparison between upper bound scenarios;

Change in risk index between 100 CC_UB scenario and 250 CC_UB scenario.

Discussion of Results

The main findings of the study are as follows:

- Pollution control plants (PCPs) are high risk infrastructure elements;
- Critical areas of the high risk include:
  - The area behind the Broughdale dyke along the North Thames;
  - The area behind the West London Dyke near the downtown Forks;
  - The Pottersburg Creek area southwest of Trafalgar Street & Clarke Road; and
  - DA 35390706 (Cell C3) that contains the Greenway PCP.
- The most critical climate change scenario is the 100-year Climate Change Upper Bound (CC_UB) scenario and it is being recommended for use in the climate change adaptation policy development and decision making.

This study was limited to the assessment of flooding related to climate change and the risk to infrastructure. However, it is important to consider social implications of flooding related to climate change as these can have an impact on public infrastructure risks and prioritization of adaptation options.

Preliminary Recommendations

The results of the study provide insight in the climate change-caused flood risk to municipal infrastructure. Various recommendations are provided to assist the City of London in developing a viable climate change adaptation policy. Recommendations are classified into three major themes: (i) engineering; (ii) operational; (iii) policy and regulatory. Although they have been classified, there are recommendations that may cross these themes.

Policy

Recommendation P1 - The City shall undertake Subwatershed Study updates (including the Central Thames) related to the Water Resources Management component and additional more detailed studies to establish the storm/drainage and SWM criteria requirements within the subwatershed boundaries.

Recommendation P2 - The City shall undertake additional more detailed studies to evaluate the risk impact of flooding from extreme storm events for selected bridges and Pollution Control Plants, The studies are also to recommend potential risk-reducing measures.

Recommendation P3 - Based on the facts that this study has not directly consider sanitary and storm network infrastructure in risk assessmentit is recommended that for those areas considered at high risk that contain a dense network of sanitary and storm infrastructure that may result in even higher risk to these areas, the City needs to undertake additional evaluation of the conveyance system infrastructures and this infrastructure be regularly inspected.

Recommendation P4 - Infrastructure may also be affected by other climate change factors including temperature extremes and shifts in freeze/thaw cycles, among others. The City is recommended to investigate these other climate change factors that may affect the region and further impact municipal infrastructure.

Recommendation P5 - It is advised that the City considers both the risk to municipal infrastructure and social vulnerability when addressing climate change adaptation and planning strategies. Although the purpose of this study is to assess the effects of flooding on municipal infrastructure, it is important to mention that physical structures are not the only element at risk during a flood event. Natural disasters have very significant social impacts as well. It is the combination of both infrastructure and social risk that could change the magnitude and spatial distribution of risk. When intersected with high infrastructure risk regions, these are areas of particular concern and both infrastructure and social risks require attention. One of these cases includes the Coves. Although this region was classified at risk, the region does not appear to experience one of the highest risks. However, the region is dominated by trailer homes, most of which require complete reconstruction after any of the flood scenarios considered in this study. These trailer homes may not be worth as much as residential structures in other flooded areas, therefore the region will show lower risk. However the people living in the Coves may be especially vulnerable. The entire community may be inundated and recovery can be especially difficult for those with limited access to resources. This is why it is important to consider social risk in combination with infrastructure risk before making any critical decisions based on this study's analysis.

Recommendation P6 - This study indicates that there is a need to consider future regulations and possible change of the regulatory floodplain to include impacts of climate change. An economic analysis is recommended to assess the consequences of changing regulations and perform the cost-benefit analysis using the results of this study – to find out the cost of risk reduction.

Recommendation P7 - The final recommendation is to initiate the process of change of the infrastructure design criteria to include climate change impacts. Risk increase identified in this study points out that the future infrastructure will have to be designed to withstand the potential impacts of extreme storm events/climate change.

Recommendation P8 Develop a Green Infrastructure Plan to incorporate an environmental/ ecological approach to water resources management and formalize a Climate Change Long Term Adaptation Strategy.

Engineering

Recommendation E1 - The land behind the Broughdale dyke is at high risk. Possible alternatives to mitigate this risk include: raising the height of the dyke; extending the dyke east to prevent encroaching floodwaters; floodproofing structures behind the dyke; temporary sandbagging efforts to increase the height of the dyke in the case of a flood event; regular maintenance and inspection. It is recommended that the area behind the dyke that may be affected be prepared for the possibility of dyke failure. This should be included in emergency plan and preparedness for this area.

Recommendation E2 - The area behind the West London dyke is at high risk. The recent repair of the dyke will contribute to its safety but will not prevent the protection from climate change-caused flooding. It is recommended that the repair of remaining sections of the dyke be completed together with: floodproofing structures behind the dyke; development of the detailed emergency management plan for temporary sandbagging efforts to increase the height of the dyke in the case of a flood event; and regular maintenance and inspection. It is recommended that the detailed emergency management planning is in place for the area behind the dyke that may be affected by the possible dyke failure.

Recommendation E3 - The CN rail embankment in Pottersburg Creek (southwest of Trafalgar St. and Clarke Rd.) backs up floodwaters and behaves like a dam. This phenomenon does not occur to such an extent in the 250 UTRCA scenario and this contributes to the great difference in risk to areas upstream of the culvert. Infrastructure not inundated in the 250 UTRCA scenario becomes inundated in the 250-yr climate change scenarios, creating the large difference in risk for DAs upstream. This is an area of high concern and a more detailed hydrologic and hydraulic study is suggested for this location. Culvert modifications and alternatives may need to be considered to mitigate the high risk of flooding. It is recommended that this region considers the use of 100 CC_UB scenario for floodplain management, decision making and regulations to capture the high risk nature of this area.

Recommendation E4 - The City would benefit from improved data collection, data documentation and data dissemination procedures. All infrastructure data should be kept in a database with consistent format and documentation procedures.

Recommendation E5 - Increasing the number of flow monitoring stations across the City may provide better input into risk assessment and provide real-time data related to flood hazard. This has potential to allow sufficient time to disseminate flood warnings and prepare for disaster management.

Recommendation E6 – Based to the variability and inconsistency in bank slopes and over-water infrastructure, it is recommended that the City resurveys the bridges and bank slopes within the City boundaries; the City should consider updating their topographic information. This would improve hydraulic calculations, floodplain accuracy and provide a more representative risk assessment.

Recommendation E7 - It is recommended that the City continue to expand the infrastructure considered in the risk analysis. Infrastructure selection for this study is driven by data availability and quality. As more detailed data becomes available the City is recommended to continue efforts to extend the risk analysis to include other infrastructure types such as public utilities, sanitary sewer networks and storm sewer networks.

Recommendation E8 - The flood scenarios considered in this risk assessment are all static events, that is, they are a snapshot of the flood at a moment in time. The City would benefit from a dynamic simulation model and risk assessment procedure to help capture the dynamic nature of flood events. Overland flow modeling would change the nature of the flood and provide additional flood impacts. There may be regions outside of the floodplain that flood as well which would require extensive overland flow analysis. This could contribute to a more complete flood model and risk assessment.

Operational

Recommendation O1 - Pollution Control Plants (PCPs) would benefit from a detailed emergency plan with regards to the critical flood scenarios in this study. In the event of a flood Greenway, Adelaide, Vauxhall and Pottersburg PCP may have limited access. There should be preparatory procedures in place to maintain safety (or potentially evacuation) at the plant. Access may also be restricted in the recovery phase of flooding due to unfavorable road conditions and should be considered in recovery plan. To maintain functioning capacity during a flood event it is recommended that all four of the aforementioned PCPs raise or make mobile their essential operational equipment. In the event of a flood these equipment will experience less damage and be able to maintain partial functionality. Any of these PCPs in the recovery stages of a flood may not be able to run at full capacity. It would be beneficial to have a flood recovery plan outlining procedures to manage and maintain the plant during this stage.

Recommendation O2 - Bridges with piers are greatly affected by scour during flood situations; it is the single most important parameter for bridge failure during high water events. Thus, it is recommended that bridges with piers be closely monitored on a regular basis for signs of scour and pier degradation; with particular emphasis on monitoring before and after a flood event of both 100 and 250 year magnitude.

Recommendation O3 - The City is advised to maintain detailed historical records of damages during high water events for all critical facilities and city-owned infrastructure. Damages to building structure, foundation, equipment, contents and lost profits can be used to improve flood damage estimates and modify flood risk assessment.

Recommendation O4 - Four schools are affected in the flood scenarios; Prince Charles Public School, Princess Anne French Immersion Public School, St. Pius X Separate School and Jeanne Sauve French Immersion Public School. These schools should have very detailed protocol and procedure in case of a flood event. These schools would benefit from a program and training in emergency response for all staff and students. It is important that there is organization and preparedness in the response to natural hazards to avoid confusion and chaos.

Recommendation O5 - Monitoring and regular inspection of the Broughdale and the West London dykes will have to be strengthen due to the fact that they will be overtopped by the climate change-caused floods.